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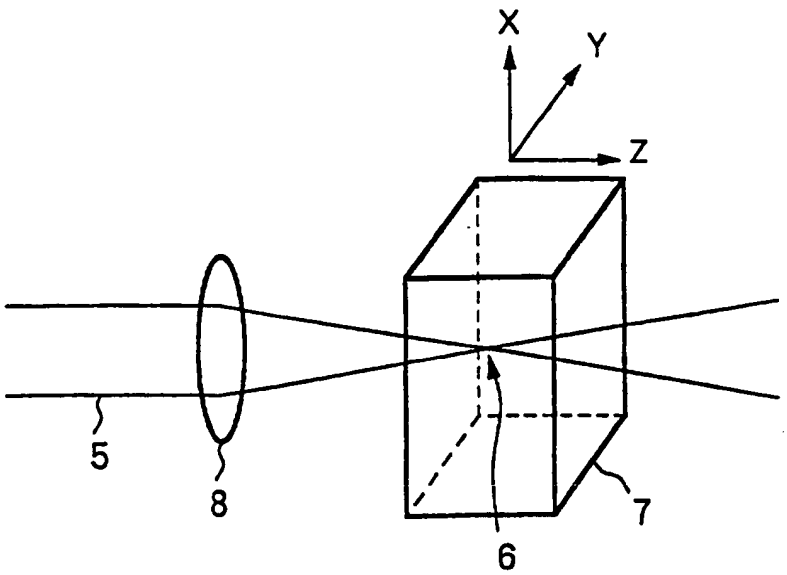
(54) OPTICAL WAVEGUIDE ARRAY AND METHOD OF MANUFACTURING THE SAME

(57) A glass **7** containing one or more of metal microparticles, semiconductor microparticles, transition metal ion, rare earth ion and anion with characteristic absorption in a wavelength region longer than 360nm is irradiated with a pulsed laser beam condensed at a focal point **6** preset in an inner part of the glass **7**. The condensed irradiation induces change of a refractive index as well as decrease of characteristic absorption in the wavelength region longer than 360nm at the focal point **6**. Such the domain is continuously formed by relatively shifting the focal point **6** with respect to the glass **7**. The continuous domains serve as optical waveguides **11**, **12**..., since optical properties are greatly different between the irradiated part and the nonirradiated part **19**.

FIG.2



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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to an optical waveguide array having the structure that a plurality of domains where characteristic absorption in a wavelength region longer than 360nm decreases together with change of a refractive index are continuously formed in inner parts of material, and a method of manufacturing such the optical waveguide array.

BACKGROUND OF THE INVENTION

[0002] An optical waveguide array having optical fibers installed in a substrate is used as a means for digital and/or image data in an optical communication system. A conventional optical fiber has the structure that a core of a higher refractive index is surrounded with a cladding layer. Due to such the structure, incident light which is emitted to the optical fiber with an angle less than a numerical aperture (NA) repeats total reflection at an interface between the core and the cladding layer, to transmit image data toward an outlet of the optical fiber.

[0003] However, light which is emitted to the optical waveguide array with an incidence angle greater than a value corresponding to the numerical aperture (NA) does not perform total reflection at the interface between the core and the cladding layer, but travels through the cladding layer to an adjacent optical fiber. Light emitted to the cladding layer also travels through the cladding layer and the core, and reaches the opposite side. Such the unfavorable travelling causes occurrence of so-called "cross-talk" that the light travels in the part where travelling shall be originally forbidden, resulting in frequent occurrence of errors in transmission of digital data, and decrease of contrast as well as degrading of image in case of transmission of image data.

[0004] Cross-talk is suppressed by provision of a light absorber between optical fibers of an optical waveguide array to absorb leaked light, as disclosed in **JP 1-180180A** and **JP 3-38963A**. In such an optical waveguide array (as shown in Fig. **1**), each core **1a** is surrounded with a cladding layer **1b** and a light-absorbing layer **1c**, a plurality of the optical fiber **1** are bound together as bundles **2**, and each bundle **2** is individually sandwiched between substrates **3** such as glass. Since leaked light is separated by the light-absorbing layer **1c**, an image is not degraded of contrast during travelling, so that an image sensor capable of reading image data with high resolution is offered.

[0005] However, there are restrictions on material of the light-absorbing layer **1c**, since the optical fiber **1** covered with the light-absorbing layer **1c** shall be good of adhesiveness to glass. In addition, a very complicated process is necessitated due to formation of the light-absorbing layer **1c** as well as adhesion of bundled optical fibers **1** to the substrates **3**.

[0006] By the way, European Patent No. 0797112A discloses production of an optical waveguide by irradiation of a glass sample with a laser beam condensed at a focal point in an inner part of the glass sample to partially increase a refractive index at the focal point. In this method, a quartz or fluoride glass is irradiated with a condensed laser beam to form an optical waveguide. Production of an optical waveguide array is anticipated in course of developing such the method to enable formation of optical waveguides in an arrayed state. However, condensed irradiation with the laser beam merely induces change of an refractive index, but cross-talk is still unresolved. Consequently, image data are transmitted in a degraded state with poor contrast.

SUMMARY OF THE INVENTION

[0007] The present invention aims at elimination of above-mentioned problems. An object of the present invention is to provide a new optical waveguide array having the inner structure that a plurality of domains where a change of a refractive index as well as decrease of characteristic absorption in a longer wavelength region occur are continuously formed by irradiating a glass, which contains an absorbing material with characteristic absorption in the longer wavelength, with a pulsed laser beam condensed at a focal point preset in inner parts of the glass.

[0008] An optical waveguide array according to the present invention comprises a glass matrix containing an absorbing material with characteristic absorption in a wavelength region longer than 360nm, and a plurality of domains, where change of a refractive index as well as decrease of characteristic absorption in a wavelength longer than 360nm occur due to transition of the absorbing material caused by irradiation with a pulsed laser beam condensed at a focal point preset in inner parts of a glass, are continuously formed in the matrix. The absorbing material may be one or more of metal microparticles, semiconductor microparticles, transition metal ions, rare earth ions and anions.

[0009] The optical waveguide array is fabricated as follows: A pulsed laser beam with an energy capable of inducing change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm is emitted to a glass containing an absorbing material with characteristic absorption in the wavelength region longer than 360nm, in the manner such that a focal point of the pulsed laser beam is adjusted to an inner part of the glass. Such irradiation is continued while relatively shifting the focal point in the glass, so as to form a continuous domain where change of the refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm occur in the inner part of the glass. Such the domain serves as an optical waveguide. After the focal point is relocated, the same irradiation is repeated to form a plurality of optical waveguides.

[0010] When a glass containing an absorbing material with characteristic absorption in a longer wavelength region is irradiated with a pulsed laser beam condensed at a focal point preset in an inner part of the glass, change of the refractive index as well as transition of the absorbing material occur at the focal point. Such an absorbing material as metal microparticle, semiconductor microparticle, transition metal ion, rare earth ion or anion has characteristic absorption in a wavelength region longer than 360nm. Condensed irradiation with the pulsed laser beam also changes a number of metal microparticle or semiconductor microparticle, and a size or transformation of the microparticle. Such the condensed irradiation also changes valence, coordination and integration of transition metal ion, rare earth ion or anion.

[0011] For instance, when a glass dispersing metal microparticles or semiconductor microparticles therein is irradiated with a condensed pulsed laser beam, the microparticles are decreased in number, reduced in size, or dissolved or ionized in a glass matrix.

[0012] Absence of the microparticles due to such dissolution or ionization causes decrease of an absorption coefficient to the same value as that of a glass free from dispersion of the microparticles, compared with a level before irradiation. Change of the microparticles in size causes change of absorption wavelength, i.e. decrease of an absorption coefficient compared with a level before irradiation.

[0013] A part subjected to condensed irradiation increases its refractive index compared with the other part which is not subjected to condensed irradiation, due to structural re-arrangement caused by the condensed irradiation, so that structure of an optical waveguide is formed in the glass. When a laser beam for transmission of image data with wavelength adjusted to a wavelength region of characteristic absorption is emitted to the processed glass, the laser beam travels along the optical waveguide at a high efficiency, since an absorption coefficient is decreased at the focal point while the other part keeps its original absorption coefficient before the condensed irradiation. In addition, light leaked out of the waveguide (the irradiated part) is trapped in the non-irradiated part, so as to inhibit occurrence of errors in data transmission. Consequently, image data can be read out with high resolution without degrading of contrast.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Fig. 1 is a schematic view illustrating a conventional optical fiber array.

[0015] Fig. 2 is a view for explaining irradiation of a glass having characteristic absorption in a wavelength region longer than 360nm with a pulsed laser beam condensed at a focal point preset in an inner part of the glass.

[0016] Fi. 3A is a bird's eye view illustrating an optical waveguide array in Example of the present invention.

[0017] Fig. 3B is a sectional view illustrating the same optical waveguide array.

[0018] Fig. 4 is a schematic view illustrating an optical waveguide array having the structure that a plurality of domains where change of an refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm occur are continuously formed in a glass with characteristic absorption in the wavelength region longer than 360nm.

[0019] Fig. 5 is a schematic view illustrating an optical waveguide array having the structure that a plurality of domains where change of a refractive index occurs are continuously formed in a glass without characteristic absorption in a wavelength region longer than 360nm.

[0020] Fig. 6A is a graph showing a absorption spectrum of a glass dispersing Au microparticles therein at a part irradiated with a condensed laser beam in comparison with a non-irradiated part.

[0021] Fig. 6B is a graph showing a absorption spectrum of a glass dispersing Cu microparticles therein at a part irradiated with a condensed laser beam in comparison with a non-irradiated part.

[0022] Fig. 6C is a graph showing a absorption spectrum of a glass dispersing Ag microparticles therein at a part irradiated with a condensed laser beam in comparison with a non-irradiated part.

PREFFERED EMBODIMENT OF THE PRESENT INVENTION

[0023] Metal microparticles to be dispersed in a glass for an optical waveguide array may be Au, Ag, Cu or Pt. Semiconductor microparticles may be CdS, CdSe, CdTe, CuCl, CuBr, ZnS or ZnSe. These microparticles may be dispersed solely or combinatively in a glass.

[0024] Condensed irradiation of a glass containing transition metal ion, rare earth ion or anion with a pulsed laser beam induces change of ion valence, a coordination state, an integrated state and so on. Characteristic absorption before the irradiation is eliminated or decreased due to such change. The condensed irradiation with the pulsed laser beam forms such the optical waveguide structure, that a refractive index at the irradiated part is higher than a value at the non-irradiated part, in an inner part of the glass. Travelling of a light signal along the optical waveguide (the irradiated part) is performed with a high efficiency, and occurrence of errors in data transmission is prevented by trapping a beam leaked out of the optical waveguide in the non-irradiated part. Consequently, an optical device capable of reading image data with high resolution without degrading of contrast is offered.

[0025] One or more of Cu^{2+}, V^{3+}, V^{4+}, Ti^{3+}, Ni^{2+}, Co^{2+}, Fe^{2+}, Fe^{3+}, Mn^{2+}, Mn^{3+}, Cr^{3+}, Cr^{6+} and Mo^{4+} may be included as transition metal ion in a glass. One or more of Pr^{3+}, Nd^{3+}, Sm^{3+}, Eu^{3+}, Dy^{3+}, Ho^{3+}, Er^{3+}, Tm^{3+}, Yb^{3+}, Ce^{3+}, Sm^{2+}, Eu^{2+} and Yb^{2+} may be included as rare

earth ion in the glass. One or more of OH^-, O^{2-} and F^- may be included as anion in the glass.

[0026] A waveguide is formed by emitting a pulsed laser to a glass containing an absorbing material with characteristic absorption in a wavelength region longer than 360nm in the manner such that a focal point of the pulsed laser beam is preset in an inner part of the glass, and relatively shifting the focal point in the inner part of the glass so as to form a continuous domain where change of a refractive index as well as decrease of characteristic absorption in the wavelength longer than 360nm occur. If a glass containing an absorbing material with characteristic absorption in a wavelength region shorter than 360nm is irradiated with a pulsed laser beam on the contrary, leaked signal light of wavelength generally longer than 360nm would not be absorbed in non-irradiated glass matrix resulting cross-talk. Furthermore, decrease of the characteristic absorption effective for a waveguide is hardly realized since the glass itself often has characteristic absorption in the wavelength region shorter than 360nm. However, a glass containing an absorbing material may be available for fabrication of an optical waveguide array, as far as condensed irradiation with a pulsed laser beam induces decrease of characteristic absorption of the absorbing material in a wavelength region longer than 360nm, with the proviso that a tail of the absorption overlaps a wavelength region longer than 360nm even if a peak of characteristic absorption is shorter than 360nm and that the glass containing such the absorbing material has a higher absorption coefficient in a wavelength region longer than 360nm compared with a glass which does not contain such the absorbing material.

[0027] A pulsed laser beam with an energy sufficient for inducing change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm is used for formation of a waveguide, although the energy depends on a kind of a glass. A peak power of the pulsed laser beam is represented by a power (W) which is a value of an output energy (J) per one pulse divided by pulse width (second), and a peak powder density is represented by a value(W/cm^2) of a peak power per a unit area (cm^2).

[0028] A peak power density is preferably within a range of 10^5-$10^{15}W/cm^2$ at a focal point in order to induce change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm. If the peak power density is less than $10^5W/cm^2$, change of a refractive index and decrease of characteristic absorption in a wavelength region longer than 360nm hardly occur at the focal point. If the peak power density exceeds $10^{15}W/cm^2$ on the contrary, change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm unfavorably occur at the other part except the focal point. Besides, it is practically difficult to emit a laser beam with an excessively big energy.

[0029] When a glass is irradiated with a pulsed laser beam with the same peak power density, the possibility to induce change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm is intensified as narrower pulse width of the pulsed laser beam. In this sense, narrower pulse width is better, and is preferably 10^{-16} second or shorter. If a glass is irradiated with a pulsed laser beam with too wider pulse width, emission of a pulsed laser beam with an excessively big energy is necessitated in order to gain the similar peak power density as that of a pulsed laser beam with narrower pulse width. Application of such the big energy causes fracture of the glass. If a glass is irradiated with a pulsed laser beam with wavelength in an absorption wavelength region of the glass, intensity of the pulsed laser beam becomes weaker as the pulsed laser beam travels in the glass along its depth direction. However, any special restrictions are not put on wavelength of a pulsed laser beam, as far as an energy with a predetermined peak power density is applied to a part of a glass which is expected to form an optical waveguide.

[0030] A pulsed laser beam with narrower pulse width, i.e. a greater repetition rate is preferable for formation of a smooth waveguide structure, so as to apply a first pulse and then a second pulse in a possible shortest time period. In this sense, a repetition rate of a pulsed laser beam is 10kHz or more (preferably 100kHz or more).

[0031] A pulsed laser beam with too small repetition rate is discretely emitted to a glass without induction of change of a refractive index necessary for formation of a continuous optical waveguide. A glass can be subjected to continuous irradiation with a pulsed laser beam by lowering a relative velocity of a glass or a focal point. However, since a second pulse is applied in an overlapping state after lapse of a predetermined time period from application of a first pulse, a part where the first pulse induced change of a refractive index would be unfavorably deformed by application of the second pulse. Such deformation causes rugged structure of an optical waveguide.

[0032] An upper limit of a repetition rate is indefinite, and a pulsed laser beam limitlessly similar to continuous light may be used. However, an energy per one pulse becomes weaker as increase of a repetition rate . In this sense, the upper limit of the repetition rate is practically determined accounting a threshold which induces change of a refractive index in a glass as well as decrease of characteristic absorption in a wavelength region longer than 360nm in comparison with an output of a pulsed laser beam to be emitted.

[0033] When a glass with characteristic absorption in a wavelength region longer than 360nm is irradiated with a pulsed laser beam in the manner such that a focal point of the pulsed laser beam is preset in an inner part of the glass, a quantity of light necessary for inducing change of a refraction index as well as transition of an absorbing material (i.e. the characteristic absorption

cause) is not gained at the other part except the focal point. Consequently, change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm selectively is limited to the focal point, while the glass keeps its original refractive index and an original state of the absorbing material at the other part except the focal point (a non-irradiated part). Due to such selective reformation, an optical waveguide structure is formed in an inner part of the glass.

[0034] A pulsed laser beam **5** emitted from a light source is condensed by a condenser lens **8** or the like so as to position its focal point **6** at an inner part of a glass **7**, as shown in Fig. 2. A domain where change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm occur is continuously formed in the inner part of the glass **7**, by relatively shifting the focal point 6 in the glass **7**. Relative movement of the focal point **6** with respect to the glass **7** may be performed by continuously shifting the glass **7** with respect to the focal point **6** of the pulsed laser beam **5**, continuously shifting the focal point in the glass **7**, or shifting both the focal point **6** and the glass **7**.

[0035] Since the domain where change of a refractive index as well as decrease of characteristic absorption occur is continuously formed in the inner part of the glass **7**, such the domain serves as an optical waveguide **11** (as shown in Fig. 3). A core diameter of the optical waveguide **11** is controlled by the focal distance of the condenser lens **6**.

[0036] A glass substrate 7 with characteristic absorption in a wavelength region longer than 360nm is used for fabrication of an optical waveguide array having a profile shown in Fig. 3**A** and a cross section shown in Fig. 3**B**.

[0037] A first optical waveguide **11** is formed in a first step wherein a focal point **6** of a pulsed laser beam **5** is relatively shifted in an inner part of a glass **7**. The focal point **6** is then relocated to another position different from an initial point of the first optical waveguide **11** and shifted in the inner part of the glass **7** along a direction parallel to the first optical waveguide **11**, to form a second optical waveguide **12** in a second step. Relocation and shifting of the focal point **6** are repeated thereafter in the same way to form an optical waveguide array **10** comprising a plurality of optical waveguides **11**, **12**... each parallel together. The inner part (irradiated part) of the glass **7** where the optical waveguides **11**, **12**... are formed changes its refractive index and decrease of characteristic absorption in a wavelength region longer than 360nm, while the other part **19** (non-irradiated part) keeps its original refractive index without decrease of characteristic absorption.

[0038] When a laser beam for transmission of image data with wavelength predetermined in a wavelength region corresponding to characteristic absorption of the non-irradiated part **19** (glass matrix) is emitted to the waveguide array **10**, the incident beam travels through the optical waveguides **11**, **12**... with high performance, since an absorption coefficient at the irradiated part (corresponding to the focal point **6**) is decreased while the non-irradiated part **19** keeps its original absorption coefficient. The laser beam leaked out of the optical waveguides **11**, **12**... is trapped in the non-irradiated part **19**. As a result, the image data can be read out with high resolution without occurrence of cross-talk which causes data errors or degrading of contrast.

Example 1 (fabrication of an optical waveguide array from a glass dispersing Au microparticles therein)

[0039] SiO_2, B_2O_3, Na_2CO_3 and Sb_2O_5 raw materials were weighed and mixed together, and an aqueous chloroauric acid solution was added to the powdery mixture to prepare glass composition of 72 parts by weight SiO_2, 18 parts by weight B_2O_3, 10 parts by weight Na_2O, 4 parts by weight Sb_2O_3 and 0.02 parts by weight Au.

[0040] The powdery mixture (400g) was put in a Pt crucible of 300cc capacity, and melted under tilting condition 2 hours at 1450°C in the open air. Uniform glass melt was shaped to a sheet of 5mm in thickness by molding it in a brass die, and then cooled. The glass sheet obtained was annealed at 450°C to release strains.

[0041] The glass sheet was set in an electric oven, heated at 5°C /minute, held 8 hours at 700°C, and then cooled as such in the oven to precipitate Au microparticles in the glass. The glass was colored to dark-red due to precipitation of Au microparticles. After the heat-treated glass was trimmed and ground, a parallelepiped sample of 10mm in length, 10mm in width and 2mm in thickness was cut off the glass sheet.

[0042] The sample was examined by absorption spectrum analysis. Its permeability to light of wavelength shorter than 580nm was 0%.

[0043] The glass sample **7** was mounted on an electromotive stage capable of moving along **X**, **Y** and **Z** directions, and irradiated with a pulsed laser beam **5** in the manner such that a focal point **6** of the pulsed laser beam **5** was adjusted to an inner part of the glass sample **7** by a condenser lens **8**. The focal point **6** was shifted with respect to the glass sample **7** along the **Z** direction (corresponding to an optical axis of the laser beam **5**), without movement of the focal point **6** along the **X** and **Z** directions. A pulsed laser beam **5** (800nm wavelength, pulse width of 1.5×10^{-13} second, a repetition rate of 200kHz and an averaged power of 500mW) oscillated from a Ti-sapphire laser excited with an argon laser was used as the pulsed laser beam **5**.

[0044] Increase of a refractive index by 0.01 at the focal point 6 was recognized by observation of the irradiated glass sample **5**. Change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer tan 360nm occurred in a very short time period of nanosecond or picosecond order.

[0045] The glass sample **7** and/or the focal point **6** were relatively shifted along the **Z** direction (an optical

axis) to form a straight domain (i.e. a first optical waveguide **11**) with an increased refractive index was formed in an inner part of the glass sample **7**.

[0046] Formation of the optical waveguide **11** was confirmed by actually emitting a laser beam of 800nm wavelength to the glass sample **7** and detecting travel of the laser beam only through the domain where change of a refractive index occurred. A near-field image at the outlet side proved that the optical guide wave **11** had cross section of 15μm in diameter (core diameter). Fig. **6A** shows a measurement result of absorption spectrum of the optical waveguide **11**. It is noted from Fig. **6A** that the optical waveguide **11** was defined by a domain where an absorption coefficient in a wavelength region of approximately 580-400nm caused by Au microparticles decreased and dark-red disappeared. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0047] A core diameter of the optical waveguide **11** was controlled by changing a focal distance of the condenser lens **8**. In the case where the glass sample **7** was irradiated with another pulsed laser beam of different wavelength (e.g. 1.3μm or 1.55μm in a wavelength region for commercial communication) instead of the pulsed laser beam 5 of 800nm, the same change of a refractive index as well as the same decrease of characteristic absorption in a wavelength longer than 360nm were also detected.

[0048] After the glass sample **7** was shaded from irradiation with the pulsed laser beam **5**, the glass sample **7** and/or the focal point **6** were relocated. The glass sample **7** and/or focal point **6** were then shifted along a direction in parallel to the first optical waveguide **11**, to form a second optical waveguide **12**. Relocation and shifting of the glass sample **7** and/or the focal point **6** were repeated to fabricate an optical waveguide array **10** having the structure that a plurality of optical waveguides **11, 12**... are arranged in parallel together and surrounded with a non-irradiated part **19** which kept its original refractive index without change of characteristic absorption.

[0049] The optical waveguide array **10** obtained in this way was examined by a test to research read-out contrast using a laser beam of 550nm wavelength. It was confirmed that the optical waveguide array performed extremely high contrast without cross talk, compared with an optical waveguide array which was fabricated using change of a refractive index only in under-mentioned Comparative Example 1.

Example 2 (fabrication of an optical waveguide array from a glass dispersing Cu microparticles therein)

[0050] SiO_2, B_2O_3, Na_2CO_3, Cu_2O, SnO raw materials were weighed and mixed together to prepare glass composition of 72 parts by weight SiO_2, 20 parts by weight B_2O_3, 8 parts by weight Na_2O, 0.5 parts by weight Cu and 0.25 parts by weight SnO.

[0051] The powdery mixture (400g) was melted with a heat and shaped to a sheet of 6mm in thickness by the same way as Example 1. The glass sheet was annealed at 450°C to release strains. The annealed glass sheet was set in an electric oven, heated at 5°C/minute, held 4 hours at 650°C, and then cooled as such in the oven to precipitate Cu microparticles in a glass matrix. The glass sheet was colored to red due to precipitation of Cu microparticles. After the heat-treated glass sheet was trimmed and ground, a sample of 10mm in length, 10mm in width and 4mm in thickness was cut off the glass sheet.

[0052] The sample was examined by absorption spectrum analysis. Its permeability to light of wavelength shorter than 620nm was 0%.

[0053] The glass sample **7** was irradiated with a condensed pulsed laser beam **5** by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was detected by observation of the irradiated glass sample **7**. Decrease of characteristic absorption in a wavelength region longer than 360nm was also noted in Example **2**, regardless very short irradiation of nanosecond or picosecond order. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by continuously shifting the glass sample **7** and/or the focal point **6** along the **Z** direction (an optical axis).

[0054] A near-field image at an outlet side proved that the formed optical waveguide **11** had cross section of **15**μm in diameter (core diameter). Fig. **6B** shows a measurement result of absorption spectrum of the optical waveguide **11**. Fig. **6B** proves formation of a domain where an absorption coefficient in a wavelength region of approximately 620-400nm caused by Cu microparticles decreased and red color disappeared. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0055] Second and following optical waveguides **12**... were formed by the same way as Example 1 after formation of the first optical waveguide **11**, to fabricate an optical waveguide array (shown in Fig. **4**) having the structure that a plurality of optical waveguides **11, 12**... were arranged in parallel together and surrounded with the non-irradiated part **19** which kept its original refractive index without decrease of characteristic absorption. The optical waveguide array **10** obtained in this way was examined by a test to research read-out contrast using a laser beam of 530nm wavelength. It was confirmed that the optical waveguide array performed extremely high contrast, compared with an optical waveguide array (under-mentioned Comparative Example 1) which was fabricated using change of a refractive index only.

Example 3 (fabrication of an optical waveguide array from a glass dispersing Ag mircroparticles therein)

[0056] SiO_2, $CaCO_3$, Na_2CO_3, Ag_2O, SnO raw materials were weighed and mixed to prepare glass compo-

sition of 72 parts by weight SiO_2, 20 parts by weight CaO, 8 parts by weight Na_2O, 0.4 parts by weight Ag, 0.2 parts by weight SnO.

[0057] The powdery mixture (400g) was put in a Pt crucible of 300cc capacity and melted under a tilting condition 2 hours at 1450°C in the open air. Uniform glass melt was molded to a sheet by the same way as Example 1. The glass sheet was set in an electric oven, heated at 5°C/minute, held 4 hours at 550°C and then cooled as such in the oven to precipitate Ag microparticles. The glass sheet was colored to yellow due to precipitation of Ag microparticles. After the heat-treated glass sheet was trimmed and ground, a glass sample of 10mm in length, 10mm in width and 3mm in thickness was cut of the glass sheet.

[0058] The glass sample was examined by absorption spectrum analysis. Its permeability to a laser beam of wavelength shorter than 420nm was 0%.

[0059] The glass sample **7** was irradiated with a condensed pulsed laser beam **5** by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was recognized by observation of the irradiated glass sample **7**. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by relative movement of the glass sample **7** or the focal point **6** along one direction. Change of a refractive index at the focal point **6** as well as decrease of characteristic absorption were also performed in a very short time period of nanosecond or picosecond order.

[0060] Formation of the optical waveguide **11** was recognized by actually emitting a laser beam of 800nm wavelength and observing travel of the laser beam only through a domain where change of a refractive index occurred. A near-field image proved that the optical waveguide **11** had cross section of 15μm in diameter (core diameter). Fig. **6C** shows a measurement result of absorption spectrum of the optical waveguide **11**. Decrease of an absorption coefficient in a wavelength region of approximately 420-360nm caused by Ag microparticles is noted in Fig. **6C**, and such the domain was not tinged with yellow. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0061] Second and following optical waveguides **12**... were formed in parallel to the first optical waveguide **11** by the same way as Example **1**, to fabricate an optical waveguide array. The optical waveguide array was examined by a test to research read-out contrast using a laser beam of 420nm. As a result, the optical waveguide array performed extremely high contrast, compared with an optical waveguide array (under-mentioned Comparative Example 2) array using change of a refractive index only.

Example 4 (fabrication of an optical waveguide array from a glass dispersing Pt microparticles therein)

[0062] SiO_2, B_2O_3, Na_2CO_3 and Sb_2O_3 raw materials were weighed and mixed together, and an aqueous platinic chloride solution was added to the powdery mixture to prepare glass composition of 72 parts by weight SiO_2, 18 parts by weight B_2O_3, 10 parts by weight Na_2O, 2 parts by weight Sb_2O_3 and 0.05 parts by weight Pt.

[0063] The powdery mixture (400g) was put in a Pt crucible and melted under a tilting condition 2 hours at 1450°C in the open air. Uniform glass melt was molded to a glass sheet by the same way as Example 1. The glass sheet was set in an electric oven, heated at 5°C/minute, held 4 hours at 600°C and then cooled as such in the oven to precipitate Pt microparticles. The glass sheet was colored to gray due to precipitation of Pt microparticles. After the glass sheet was trimmed and ground, a sample of 10mm in length, 10mm in width and 4mm in thickness was cut off the glass sheet.

[0064] The glass sample was examined by absorption spectrum analysis. Its permeability to visible light of 750-400nm is at a relatively low level of 20% in average.

[0065] The glass sample **7** was then irradiated with a condensed pulsed laser beam **5** by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was recognized by observation of the irradiated glass sample **7**. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by relative movement of the glass sample **7** or the focal point **6** along one direction. Change of a refractive index at the focal point **6** as well as decrease of characteristic absorption were performed in a very short time period of nanosecond or picosecond order, also in this case.

[0066] Formation of the optical waveguide **11** was recognized by actually emitting a laser beam of 800nm wavelength to the glass sample **7** and observing travel of the laser beam only through a domain where change of a refractive index occurred. A near-field image proved that the optical waveguide **11** had cross section of **15** μm in diameter (core diameter). Decrease of an absorption coefficient in a wavelength region of approximately 750-400nm caused by Pt microparticles was recognized from a measurement result of absorption spectrum, and such the domain was not tinged with gray. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0067] Second and following optical waveguides **12**... were formed in parallel to the first optical waveguide **11** by the same way as Example **1**, to fabricate an optical waveguide array (shown in Fig. **4**). The optical waveguide array was examined by a test to research read-out contrast using a laser beam of 600nm wavelength. As a result, the optical waveguide performed extremely high contrast, compared with an optical waveguide (under-mentioned Comparative Example **2**) array using change of a refractive index only.

Example **5** (fabrication of an optical waveguide array from a glass dispersing CuCl microparticles therein)

[0068] SiO_2, Al_2O_3, B_2O_3, Li_2CO_3, Na_2CO_3, K_2CO_3, CuCl and SnO raw materials were weighed and mixed

together, to prepare glass composition of 65 parts by weight SiO_2, 6 parts by weight Al_2O_3, 17 parts by weight Ba_2O_3, 4 parts by weight Li_2O, 4 parts by weight Na_2O, 4 parts by weight K_2O, 0.5 parts by weight CuCl and 0.2 parts by weight SnO.

[0069] The powdery mixture (400g) was put in a Pt crucible of 300cc capacity and melted under a tilting condition 2 hours at 1450°C in the open air. Uniform glass melt was molded to a glass sheet by the same way as Example 1. The glass sheet was set in an electric oven, heated at 5°C/minute, held 4 hours at 550°C and then cooled as such in the oven to precipitate CuCl microparticles. After the glass sheet was trimmed and ground, a glass sample of 10mm in length, 10mm in width and 4mm in thickness was cut off the glass sheet

[0070] The glass sample was examined by absorption spectrum analysis. Its permeability to light of wavelength shorter than 380nm was 0%.

[0071] The glass sample **7** was then irradiated with a condensed pulsed laser beam **5** by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was recognized by observation of the irradiated glass sample **7**. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by relative movement of the glass sample **7** or the focal point **6** along one direction. Change of a refractive index at the focal point **6** as well as decrease of characteristic absorption were performed in a very short time period of nanosecond or picosecond order, also in this case.

[0072] Formation of the optical waveguide **11** was recognized by actually emitting a laser beam of 800nm wavelength to the glass sample **7** and observing travel of the laser beam only through a domain where change of a refractive index occurred. A near-field image at an outlet side proved that the optical waveguide **11** had cross section of 15μm in diameter (core diameter). Decrease of an absorption coefficient in a wavelength region of approximately 360-380nm caused by CuCl microparticles was recognized from a measurement result of absorption spectrum. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0073] The same change of a refractive index as well as the same decrease of characteristic absorption in a wavelength region longer than 360nm were also detected, when the glass sample 7 was irradiated with a second harmonic of 400nm wavelength or a laser beam of 1.3μm or 1.55μm in a wavelength region for commercial transmission instead of the laser beam of 800nm wavelength.

[0074] Second and following optical waveguides **12**... were formed in parallel to the first optical waveguide **11** by the same way as Example **1**, to fabricate an optical waveguide array (shown in Fig. **4**). The optical waveguide array was examined by a test to research read-out contrast using a laser beam of 380nm. As a result, the optical waveguide array performed extremely high contrast, compared with an optical waveguide array (under-mentioned Comparative Example **3**) using change of a refractive index only.

Example 6 (fabrication of an optical waveguide from a glass containing Co^{2+} ion)

[0075] SiO_2, B_2O_3, Na_2O_3 and CoO raw materials were weighed and mixed together to prepare glass composition of 72 parts by weight SiO_2, 20 parts by weight B_2O_3, 8 parts by weight Na_2O and 0.05 parts by weight CoO. The powdery mixture (400g) was put in a Pt crucible of 300cc capacity, and melted under a tilting condition 2 hours at 1450°C in the open air. Uniform glass melt was poured in a brass die and shaped to a sheet of 6mm in thickness. After the glass sheet was cooled, it was annealed at 450°C to release strains. After the annealed glass sheet was trimmed and ground, and a glass sample of 10mm in length, 10mm in width and 2mm in thickness was cut off the glass sheet.

[0076] The glass sample was examined by absorption spectrum analysis. Its permeability to light of 550-700nm was 0% due to inclusion of Co^{2+} which had an absorption band in a wavelength region of 550-700nm.

[0077] The glass sample **7** was then irradiated with a condensed pulsed laser beam **5** by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was recognized by observation of the irradiated glass sample **7**. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by relative movement of the glass sample **7** or the focal point **6** along one direction. Change of a refractive index at the focal point **6** as well as decrease of characteristic absorption were performed in a very short time period of nanosecond or picosecond order, also in this case.

[0078] Formation of the optical waveguide **11** was recognized by actually emitting a laser beam of 800nm wavelength to the glass sample **7** and observing travel of the laser beam only through a domain where change of a refractive index occurred. A near-field image at an outlet side proved that the optical waveguide **11** had cross section of 15μm in diameter (core diameter). Decrease of an absorption coefficient in a wavelength region of approximately 700-550nm caused by Co^{2+} ion was recognized from a measurement result of absorption spectrum, and the domain was not tinged with blue. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0079] Second and following optical waveguides **12**... were formed in parallel to the first optical waveguide **11** by the same way as Example **1**, to fabricate an optical waveguide array (shown in Fig. **4**). The optical waveguide array was examined by a test to research read-out contrast using a laser beam of 650nm wavelength. The optical waveguide array performed extremely high contrast, compared with an optical waveguide array (under-mentioned Comparative Example **1**) using change of a refractive index only.

Example 7 (fabrication of an optical waveguide array from a glass containing Ni^{2+} ion)

[0080] SO_2, B_2O_3, Na_2O_3 and NiO raw materials were weighed and mixed together to prepare glass composition of 72 parts by weight SiO_2, 20 parts by weight B_2O_3, 8 parts by weight Na_2O, 0.2 parts by weight NiO. The powdery mixture (400g) was put in a Pt crucible of 300cc capacity, and melted under a tilting condition 2 hours at 1450°C in the open air. Uniform glass melt was poured in a Pt die and shaped to a sheet by the same way as Example 6. After the glass sheet was trimmed and ground, a glass sample of 10mm in length, 10mm in width and 5mm in thickness was cut off the glass sheet.

[0081] The glass sample was examined by absorption spectrum analysis. Its permeability to light of 450-550nm was 0% due to inclusion of Ni^{2+} which had an absorption band in a wavelength region of 450-550nm.

[0082] The glass sample 7 was then irradiated with a condensed pulsed laser beam 5 by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was recognized by observation of the irradiated glass sample **7**. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by relative movement of the glass sample **7** or the focal point **6** along one direction. Change of a refractive index at the focal point **6** as well as decrease of characteristic absorption were performed in a very short time period of nanosecond or picosecond order, also in this case.

[0083] Formation of the optical waveguide **11** was recognized by actually emitting a laser beam of 800nm wavelength to the glass sample **7** and observing travel of the laser beam only through a domain where change of a refractive index occurred. A near-field image at an outlet side proved that the optical waveguide **11** had cross section of 15μm in diameter (core diameter). Decrease of an absorption coefficient in a wavelength region of approximately 650-450nm caused by Ni^{2+} ion was recognized from a measurement result of absorption spectrum, and the domain was not tinged with brown. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0084] Second and following optical waveguides **12**... were formed in parallel to the first optical waveguide **11** by the same way as Example **1**, to fabricate an optical waveguide array (shown in Fig. **4**). The optical waveguide array was examined by a test to research read-out contrast using a laser beam of 550nm wavelength. The optical waveguide array performed extremely high contrast, compared with an optical waveguide array (under-mentioned Comparative Example 1) using change of a refractive index only.

Example 8 (fabrication of an optical waveguide array from a glass containing Pr^{3+} ion)

[0085] ZrF_4, BaF_2, LaF_3, AlF_3, NaF and PrF_3 raw materials were weighed and mixed together to prepare glass composition of 53mol% ZrF_4, 20mol% BaF_2, 4mol% LaF_3, 3mol% AlF_3, 20mol% NaF and 1mol% PrF_3.

[0086] The powdery mixture (500g) was put in a Pt crucible of 300cc capacity, and melted under a tilting condition 1 hour at 900°C in a nitrogen atmosphere. Uniform glass melt was poured in a brass die, shaped to a sheet of 5mm in thickness, and then cooled. The glass sheet obtained in this way was annealed at 260°C to release strains. After the annealed glass sheet was trimmed and ground, a sample of 10mm in length, 10mm in width and 3mm in thickness was cut off the glass sheet.

[0087] The glass sample was examined by absorption spectrum analysis. Its permeability to light of 450-550nm was 5% due to inclusion of Pr^{3+} which had an absorption band in a wavelength region of 450-550nm.

[0088] The glass sample **7** was then irradiated with a condensed pulsed laser beam **5** by the same way as Example **1**. Increase of a refractive index by 0.01 at the focal point **6** was recognized by observation of the irradiated glass sample **7**. A straight optical waveguide **11** was formed in an inner part of the glass sample **7** by relative movement of the glass sample **7** or the focal point **6** along one direction. Change of a refractive index at the focal point **6** as well as decrease of characteristic absorption were performed in a very short time period of nanosecond or picosecond order, also in this case.

[0089] Formation of the optical waveguide **11** was recognized by actually emitting a laser beam of 800nm wavelength to the glass sample **7** and observing travel of the laser beam only through a domain where change of a refractive index occurred. A near-field image at an outlet side proved that the optical waveguide **11** had cross section of 15μm in diameter (core diameter). Decrease of an absorption coefficient in a wavelength region of approximately 550-450nm caused by Pr^{3+} ion was recognized from a measurement result of absorption spectrum, and the domain was not tinged with yellowish green. On the other hand, change of permeability was not detected at the non-irradiated part **19**.

[0090] Second and following optical waveguides 12... were formed in parallel to the first optical waveguide **11** by the same way as Example **1**, to fabricate an optical waveguide array (shown in Fig. **4**). The optical waveguide array was examined by a test to research read-out contrast using a laser beam of 500nm wavelength. The optical waveguide array performed extremely high contrast, compared with an optical waveguide array (under-mentioned Comparative Example **4**) array using change of a refractive index only.

Comparative Example **1**

[0091] SiO_2, B_2O_3, Na_2O and Sb_2O_3 raw materials were weighed and mixed together to form the same

glass matrix as Example **1** except absence ofAu (i.e. 72 parts by weight SiO_2, 18 parts by weight B_2O_3, 10 parts by weight Na_2O and 4 parts by weight Sb_2O_3). The powdery mixture (400g) was put in a Pt crucible of 300cc capacity, and melted under a tilting condition 2 hour at 1450° C in the open air. Uniform glass melt was poured in a brass die, shaped to a sheet of 5mm in thickness, and then cooled. The glass sheet obtained in this way was annealed at 450°C to release strains. After the annealed glass sheet was trimmed and ground, a glass sample of 4mm in thickness was cut off the glass sheet.

[0092] The glass sample was irradiated with a condensed pulsed laser beam under the same conditions as Example **1**, to form an optical waveguide in an inner part of the glass sample.

[0093] Formation of a domain **21** (shown in Fig. 5) where change of a refractive index occurred was recognized by observation of the irradiated glass sample. Such the change of a refractive index was not detected at a non-irradiated part **29**. A plurality of optical waveguides were formed in the same way as Example **1**, to fabricate an optical waveguide array. The optical waveguide array was examined by a test to research read-out contrast using light of 550nm. Due to cross talk, the read-out contrast was very weak compared with Example **1**, since change of a refractive index only was effective for read-out without decrease of characteristic absorption derived from valence change of Au.

Comparative Example 2

[0094] SiO_2, $CaCO_3$, Na_2CO_3 and SnO raw materials were weighed and mixed together to form the same glass matrix as Example 3 except absence of Ag (i.e. 72 parts by weight SiO_2, 20 parts by weight CaO, 8 parts by weight Na_2O and 0.2 parts by weight SnO). The powdery mixture (400g) was put in a Pt crucible of 300cc capacity and melted under a tilting condition 2 hour at 1450°C in the open air. Uniform glass melt was cast to a sheet by the same way as Example 3. After the glass sheet was trimmed and ground, a glass sample of 3mm in thickness was cut off the glass sheet.

[0095] The glass sample was irradiated with a condensed pulsed laser beam under the same conditions as Example 3, to form an optical waveguide in an inner part of the glass sample.

[0096] Formation of a domain **21** (shown in Fig. 5) where change of a refractive index occurred was recognized by observation of the irradiated glass sample. Such the change of a refractive index was not detected at a non-irradiated part **29**. A plurality of optical waveguides were formed in the same way as Example **3**, to fabricate an optical waveguide array. The optical waveguide array was examined by a test to research read-out contrast using light of 420nm. The read-out contrast was very weak compared with Example 3, since change of a refractive index only was effective for read-out without decrease of characteristic absorption.

Comparative Example 3

[0097] SiO_2, Al_2O_3, B_2O_3, $LiCO_3$, Na_2O_3, K_2CO_3 and SnO raw materials were weighed and mixed together to form the same glass matrix as Example 5 except absence of CuCl microparticles (i.e. 65 part by weight SiO_2, 6 parts by weight Al_2O_3, 17 parts by weight B_2O_3, 4 parts by weight Li_2O, 4 parts by weight Na_2O, 4 parts by weight K_2O and 0.2 parts by weight SnO). The powdery mixture (400g) was put in a Pt crucible of 300cc capacity, and melted under a tilting condition 2 hour at 1450°C in the open air. Uniform glass melt was cast to a sheet by the same way as Example 5. After the glass sheet was trimmed and ground, a glass sample of 4mm in thickness was cut off the glass sheet.

[0098] The glass sample was irradiated with a condensed pulsed laser beam under the same conditions as Example 5, to form an optical waveguide in an inner part of the glass sample.

[0099] Formation of a domain **21** (shown in Fig. 5) where change of a refractive index occurred was recognized by observation of the irradiated glass sample. Such the change of a refractive index was not detected at a non-irradiated part **29**. A plurality of optical waveguides were formed in the same way as Example **5**, to fabricate an optical waveguide array. The optical waveguide array was examined by a test to research read-out contrast using light of 380nm. The read-out contrast was very weak compared with Example **5**, since change of a refractive index only was effective for read-out without decrease of characteristic absorption.

Comparative Example 4

[0100] High-purity ZrF_4, BaF_2, LaF_3, AlF_3 and NaF raw materials were weighed and mixed together to form the same glass matrix as Example 8 except absence of PrF_3 (i.e. 53mol% ZrF_4, 20mol% BaF_2, 4mol% LaF_3, 3mol% AlF_3 and 20mol% NaF). The powdery mixture (400g) was put in a Pt crucible of 300cc capacity, and melted under a tilting condition 2 hour at 900°C in a nitrogen atmosphere. Uniform glass melt was poured in a brass die and cast to a sheet of 5mm in thickness. After the glass sheet was cooled, it was annealed at 260°C to release strains. A glass sample of 3mm in thickness similar to Example 8 was cut off the glass sheet.

[0101] The glass sample was irradiated with a condensed pulsed laser beam under the same conditions as Example 8, to form an optical waveguide in an inner part of the glass sample.

[0102] Formation of a domain **21** (shown in Fig. 5) where change of a refractive index occurred was recognized by observation of the irradiated glass sample. Such the change of a refractive index was not detected at a non-irradiated part **29**. A plurality of optical waveguides were formed in the same way as Example **8**, to fabricate an optical waveguide array. The optical waveguide array was examined by a test to research

read-out contrast using light of 500nm. The read-out contrast was very weak compared with Example **8**, since change of a refractive index only was effective for read-out without decrease of characteristic absorption.

INDUSTRIAL APPLICATION

[0103] According to the present invention as above-mentioned, a glass with characteristic absorption in a wavelength region longer than 360nm is irradiated with a pulsed laser beam which is condensed at a focal point preset in an inner part of the glass, to form a continuous domain acting as an optical waveguide due to change of a refractive index as well as decrease of characteristic absorption in a wavelength longer than 360nm. An optical waveguide array is fabricated by formation of a plurality of such the waveguides. Since the optical waveguide array fabricated in this way has the structure that the waveguides are surrounded with non-irradiated parts capable of absorbing the leaked light and greatly different in optical properties, it is used as a product with a high reliability without occurrence of cross-talk. In addition, such the optical waveguide array can be fabricated with high productivity by a simplified process, compared with a conventional optical waveguide array provided with a light-absorbing layer. Furthermore, wavelength of light to be transmitted without cross-talk can be freely predetermined by proper selection of a glass with characteristic absorption in a wavelength region longer than 360nm.

Claims

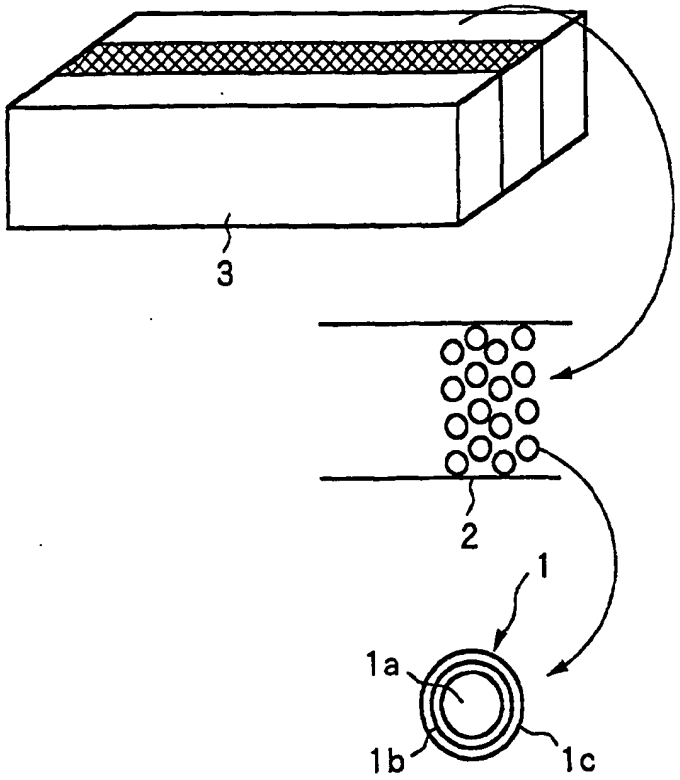
1. An optical waveguide array comprising a glass matrix which contains a light absorbing material with characteristic absorption in a wavelength region longer than 360nm, and having a plurality of domains each continuously formed in said glass matrix by irradiation with a pulsed laser beam condensed at a focal point preset in an inner part of said glass matrix to induce change of a refractive index as well as decrease of characteristic absorption in a wavelength region longer than 360nm.

2. The optical waveguide array according to Claim 1, wherein the light absorbing material is one or more of metal microparticles, semiconductor microparticles, transition metal ion, rare earth ion and anion.

3. A method of fabricating an optical waveguide array, which comprises the steps of:

   providing a glass containing light absorbing material with characteristic absorption in a wavelength region longer than 360nm;
   irradiating said glass with a pulsed laser beam with an energy sufficient to induce change of a refractive index as well as decrease of characteristic absorption in said wavelength region longer than 360nm, in the manner such that a focal point of said pulsed laser beam is preset in an inner part of said glass; and
   relatively shifting said focal point in the inner part of said glass to form a continuous domain where change of a refractive index as well as decrease of characteristic absorption in said wavelength region longer than 360nm occur.

FIG.1



PRIOR ART

FIG.2

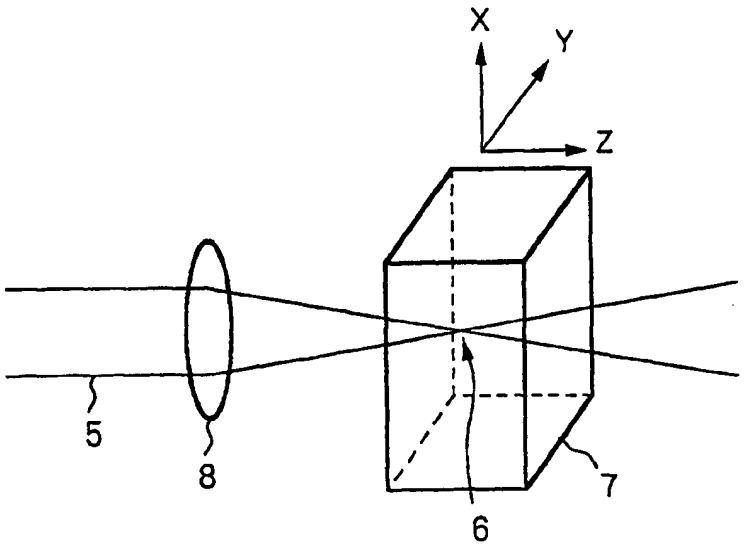


FIG.3A

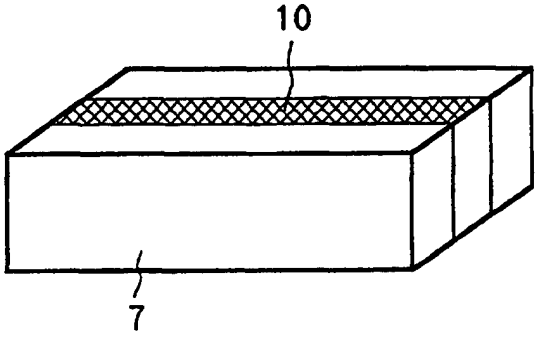


FIG.3B

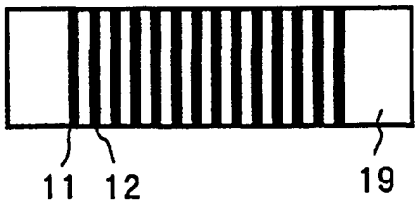


FIG.4

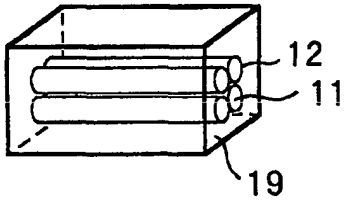


FIG.5

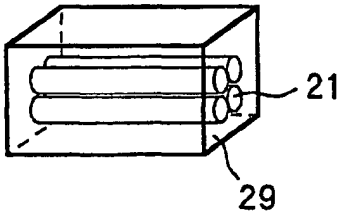


FIG.6A

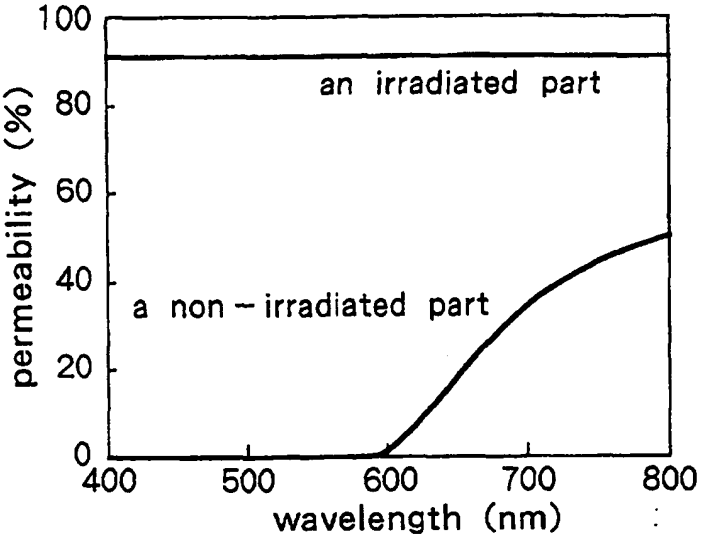


FIG.6B

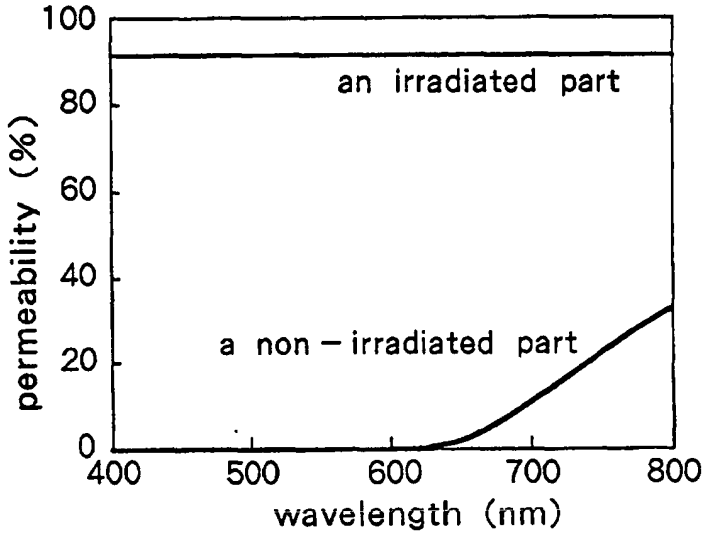
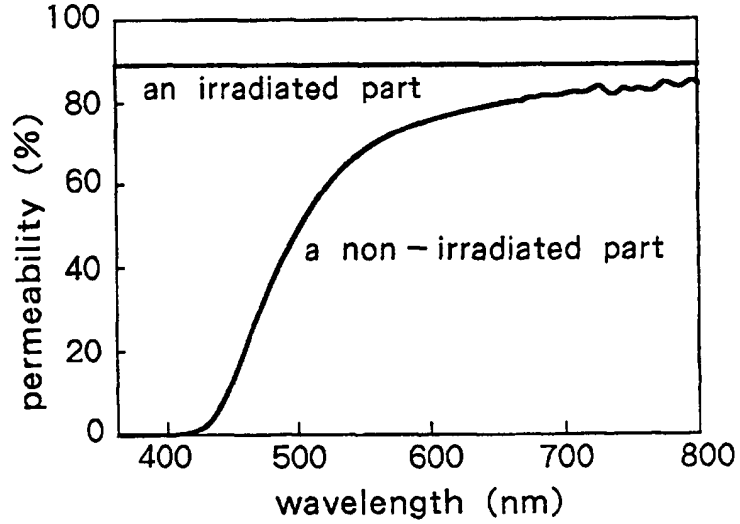


FIG.6C



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP99/00377

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[6] G02B6/04, G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[6] G02B6/04-6/08, G02B6/12-6/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1999 Toroku Jitsuyo Shinan Koho 1994-1999
Kokai Jitsuyo Shinan Koho 1971-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 63-128303, A (Toshiba Corp.), 31 May, 1988 (31. 05. 88), Claims ; Fig. 3 (Family: none)	1-3
Y	JP, 9-311237, A (Japan Science and Technology Corp.), 2 December, 1997 (02. 12. 97), Fig. 1 & EP, 797112, A1 & AU, 9715177, A & CA, 2200155, A	1-3
A	JP, 2-251907, A (The Fujikura Cable Works, Ltd.), 9 October, 1990 (09. 10. 90), Page 2, lines 14 to 17 ; Fig. 1 (Family: none)	2
A	JP, 57-208511, A (Sumitomo Electric Industries,Ltd.), 21 December, 1982 (21. 12. 82) & EP, 68176, A & DE, 3270844, G & CA, 1209090, A	2

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 April, 1999 (08. 04. 99)	20 April, 1999 (20. 04. 99)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP99/00377

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, 62-7005, A (Hitachi Cable,Ltd.), 14 January, 1987 (14. 01. 87), Claims (Family: none)	2
A	WO, 96/09563, A1 (BRITISH TELECOMMUNICATIONS), 28 March, 1996 (28. 03. 96) & EP, 782713, A1 & EP, 822425, A2 & EP, 822426, A2 & US, 5841928, A	1-3
A	JP, 8-334641, A (Fujikura Ltd.), 17 December, 1996 (17. 12. 96), Par. Nos. [0015] to [0019] ; Fig. 1 (Family: none)	1-3
A	JP, 9-178901, A (Tri-Chemical Lab,Inc.), 11 July, 1997 (11. 07. 97), Par. No. [0038] (Family: none)	1-3